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5th Workshop on Metallization for Crystalline Silicon Solar Cells

# Summary of the 5th Workshop on Metallization for Crystalline Silicon Solar Cells

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**Abstract**

The 5th Metallization Workshop took place in Constance, Germany on 20 and 21 October 2014 and provided an overview of research and development in the field of solar cell metallization. Enhanced understanding of contact structure and formation was obtained thanks to new characterization techniques. Great progress in metallization technologies was also reported. Screen printing technology is continuing its trajectory of continuous improvement, notably with fine-line screen printing (linewidth < 50 µm) becoming a reality. Ni/Cu plating technology is also progressing fast, with many of the technical barriers to adoption being successfully removed. Finally, the workshop also highlighted the move towards a module-centric design of solar cell metallization, targeting high performance and low cost at module level.


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*Keywords:* Metallization; silicon solar cells

## 1. Introduction

Photovoltaics technology continues to grow in importance, with more than 40 GW in new capacity installed in 2014. This development is enabled by a reduction of cost per Watt of generated electricity. Solar cell metallization

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is a key aspect of this evolution, because it has a strong impact on both cost and performance. Since 2008, the authors organize a workshop that brings together experts in crystalline silicon solar cell metallization, which has proved to be an important forum in this specialized field, fostering knowledge sharing, networking and collaboration. The fifth edition of the Metallization Workshop on Metallization for Crystalline Silicon Solar Cells took place on 20 and 21 October 2014, in Constance, Germany. There were 130 participants, 34 contributions, a debate session in which hot topics were discussed in small groups, and many informal discussions between experts. In this paper, we summarize the workshop while situating the contributions in the overall status of metallization in research and industry. Note that all presentations and posters are downloadable for free from www.metallizationworkshop.info.

## 2. Fundamental understanding of screen printed contacts

As in previous workshop editions, a substantial part of the workshop was devoted to contributions aiming to understand the fundamental aspects of screen printed Ag metallization. Although the technology was adopted by the solar cell manufacturing industry in the 1980'ies, has become a standard and mature technology, and has been steadily improved over the years, the understanding of both contact formation and exact microscopic conduction mechanism is still incomplete. In particular, a long standing discussion is still unresolved about what is the dominant conduction mechanism of screen printed Ag contacts on P-doped emitters. During the final thermal treatment of the screenprinted Ag paste (the 'firing') Ag crystallites grow into the Si surface, and those crystallites provide a good contact between the Si and the bulk Ag in the fingers [1, 2]. It was also observed that the thin glass layer between silicon and bulk Ag in the fingers contains extremely small particles ('nano-colloids'), and it was hypothesized that current mainly occurred through nano-colloids-assisted multi-step tunneling [3]. Research has not yet led to a consensus on this topic. There is mounting evidence that many of the contacts made with modern screen printing pastes with low contact resistance have a thin interfacial glass layer with Ag nano-colloids [4-8]. However models suggest that tunneling through a thin glass layer with Ag colloids is not possible as the distance between the nano-colloids is too large to enable significant current (at least for classical tunneling models) [9]. Temperature-dependent measurements have not yet provided a consistent answer to the puzzle [6, 8, 9]. While field emission-based models (consistent with Ag crystallite-dominated current paths) can explain measured current flows at low temperatures, they fail temperatures above 300 K [9]. A mechanism explaining why screenprinted Ag contacts often are improved upon forming gas annealing was presented. A phenomenon of formation of Ag particles through reduction was observed, leading to decoration of pores in the glass layer and creation of additional current conduction paths [10].

Emerging solar cell structures such as N-PERT cells require screen printed low ohmic contacts on highly B- (p-type) doped regions instead of P-doped (n-type), which is more challenging. Introducing some Al in the Ag paste was shown in the past to be an effective way of reducing contact resistance [11]. At the workshop, great progress was reported in understanding the formation of such contacts. A model was presented that could explain all experimental observations. In this model, contacts grow in localized areas through openings of the $SiN_x$:H coating, and $SiN_x$:H acts as a mould during the growth of the Ag/Al contacts spots (Fig. 1) [12-15]. Furthermore, it was shown that increasing the Al content limits the densification of the screenprinted metal and leads to modified glass distribution in the interface structure [16, 17].

The important topic of metallization durability on module level upon aging was also discussed. Evidence was presented that degradation of screen printed Ag fingers in damp heat conditions is related to the chemical reaction between a degradation product of EVA and screen printed Ag, and that it can be avoided altogether by selecting an alternative encapsulant [18].

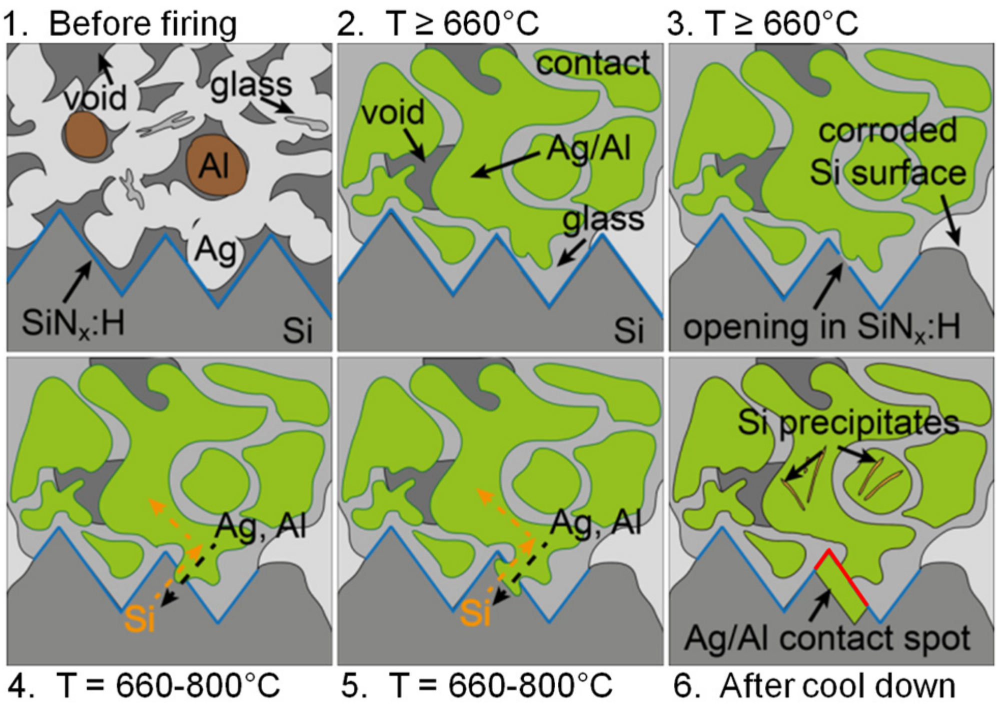


Fig. 1 : Model for contact formation of screen printed AgAl contacts [13]. Reproduced with permission from the University of Konstanz.

## 3. Screen printing technology

As the workhorse of solar cell metallization, screen printing technology is constantly being further developed and improved. One important effort is geared towards reduction of linewidth, improving screens, Ag pastes and printing process. Several contributions at the workshop demonstrated that a linewidth of 35 µm is already achieved in the laboratory while state-of-the-art industrial processes lead to 50 µm linewidth (Fig. 2) [19-23]. In order to combine fine linewidth and high aspect ratio, stencil printing [24, 25] and double printing (two fine-line prints on top of each other) are being developed and implemented, both leading to impressive results, with the latter appearing most mature today [20, 21].

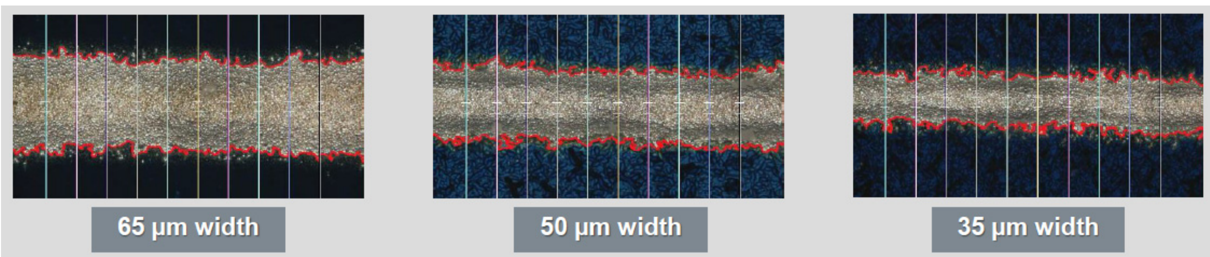


Fig. 2 : Microscope pictures of screen printed Ag fingers of different widths [19]. Reproduced with permission from Heraeus Deutschland

With the decreasing linewidth, one might expect contact resistance to increase because of limited contact area and start affecting significantly solar cell performance through higher resistive losses. However, it was shown at the workshop that with present linewidth range, as well as present paste and emitter technology, this is not yet a performance limiting factor [24-26].

A new topic in the field of screen printed metallization is the development and application of screen printable pastes based on Cu instead of Ag [5, 27-30]. These pastes are designed to prevent oxidation of the Cu particles and Cu diffusion into the solar cells. Hence, they are low temperature pastes and do not reach as low resistivities as Ag pastes, but they do allow excellent solar cell performance when used for the busbars in a two steps metallization process where fingers are first formed on the cells.

## 4. Contacts to p-type by local BSF alloying

An increasingly important topic in solar cell manufacturing is the formation of local Al-Back Surface Field by Si-Al because of the introduction of Passivated Emitter and Rear Cells in production. Such local alloying is a complex process and many undesirable effects can occur, such as the formation of a BSF region that is too deep, or the creation of voids between the highly doped Si and the Al, which can have a dramatic impact on solar cell performance. In past years, a good understanding of the phenomena at play has been reached and predictive models have been proposed. However it remains important to be able to analyze locally alloyed contacts and diagnose problems both in lab and in manufacturing. At the workshop, two non-destructive characterization techniques were introduced for void detection, and their advantages and limitations were discussed [31].

Contact resistance at local contacts potentially can have a dramatic impact on PERC cells performance, but it is not easy to determine. Often, macroscopic measurements of the overall resistance are made and a model linking resistance at a local contact and overall series resistance is used to infer the local contact resistance from them, taking the contact pattern into account. At the workshop, it was explained why previous models tended to overestimate contact resistance and an improved model was presented [32, 33].

## 5. Ni/Cu plated contacts

While screen printing remains a dominant technology in the field of solar cell metallization, electrochemical metal deposition (‘plating’) is seen by many as likely to replace screen printing in the long term, as it enables higher performance and the use of lower cost metals.

In the most developed approach to plated cells, silicon nitride is first locally removed where metallization is going to come, a thin layer of Ni is deposited on the exposed Si and annealed to form Ni silicide, and Cu is grown electrochemically to create the bulk of the contact. While, in the previous editions of the workshops, many challenges had been highlighted that needed to be solved before introduction in manufacturing, several contributions at this $5^{th}$ workshop showed that most of those challenges are being tackled if not already solved.

An important risk with Cu-based metallization is the possible diffusion of Cu into the Si, impacting device performance. It was shown at the workshop that PECVD SiNx effectively stops Cu diffusion, and that in a 0.2 µm Ni deposition in the area where SiNx has been removed could also provide adequate barrier properties [34, 35]. Therefore, accelerated aging tests indicated that properly designed Ni/Cu plated metallization could yield the stability necessary for long term operation.

Another concern is the potential poor adhesion of metallization, which in the past was cause of a resounding failure of one of the market introduction attempts of a plated solar cell technology. At the workshop some excellent adhesion results were presented, both for Ni deposited by sputtering [36] and Ni deposited electrochemically [37]. In the latter contribution, it was shown that adhesion was such that peeling off a soldered ribbon from a busbar led to breakage in the silicon at comparably high pull forces. Finger adhesion was also shown to be excellent for the right plating conditions, as illustrated in Fig. 3. A stylus-based method was proposed at the workshop to provide quantitative data on finger adhesion and help determine failure modes [38, 39].

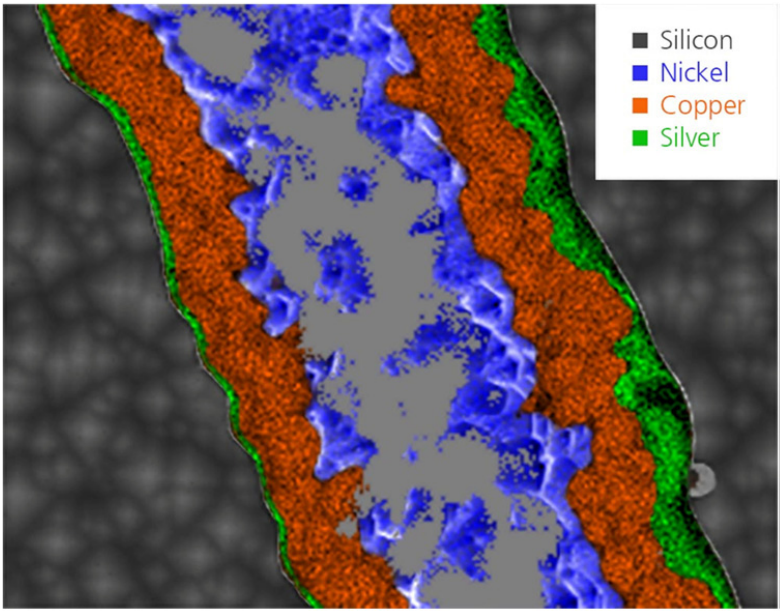


Fig. 3 : SEM-EDX picture of the bottom surface of a Ni/Cu plated finger that was intentionally pulled off from a solar cell. Note the presence of Si in the region where Ni silicide was formed, indicating cohesive failure in the Si and excellent adhesion at the Ni silicide/silicon interface. Picture reproduced with permission from Rena Technologies GmbH and Fraunhofer Institute for Solar Energy Systems ISE [37]

In the past, plating metallization procedures were always seen as very complex, with multiple annealing and wet chemical steps. Recently, process sequences have been developed that enormously simplify the process [37, 40-43], a typical sequence consisting of a laser ablation step, plating of the whole metal stack (that can be done in principle in a single wet chemical process equipment) followed by a single annealing step in nitrogen. With such a process, p-type Cz PERC solar cells with efficiencies well above 20.5 % were made, with the best cell reaching 21 % [37]. Whereas in the past, plating expertise for solar cells was confined to very few labs, general plating knowledge and good practices are becoming more widespread, partly thanks to contributions at the Metallization Workshop, see for example reference [44, 45].

Finally, good durability and reliability results of full size modules need to be available before massive investment in the technology. Such data is starting to become available, with for instance full size module made with Cu plating cells shown to pass IEC standard requirements for damp heat and thermal cycling without any degradation [37, 42].

The progress reported earlier on Ni/Cu plating was obtained on cells with conventional homojunction devices. However, this type of metallization seems ideally suited for heterojunction (HJ) solar cells (c-Si cells with amorphous Si emitter and BSF). This is related to the temperature sensitivity of those devices, which degrade already at intermediate temperatures (> ~ 250 °C). Conventional screen printing pastes cannot be used as they need to be fired at high temperature. That is why low temperature Ag pastes have been used for HJ solar cells, but they result in a much higher resistivity material after annealing (a factor 3 in the best case), and they are more expensive than high temperature pastes. Therefore, one needs more of a more expensive material, resulting in a cost disadvantage for that technology. As Ni/Cu plating metallization does not require high temperatures and moreover has low material cost, it seems a perfect fit for heterojunction cells. There are however challenges to implement plating on such cells. Unlike for homojunction cells where patterning can be achieved in a relatively easy way through laser ablation and selective Ni deposition or silicidation, a rather complex (and therefore expensive) patterning process has to be used. Moreover, contact resistance and adhesion of those contacts on the transparent conductive oxide layer that is needed for these devices tend to be poorer than with screen printed contacts [46]. The problems were discussed at the workshop and progress on solving them was presented. It was for instance shown that the detrimental impact of plating chemicals on the transparent conductive oxide could be avoided by carefully selecting the baths and implementing some process changes [47]. An innovative and potentially low cost inkjet patterning technology was also presented and implemented in a proof-of-concept heterojunction device [48, 49].

## 6. Alternative metallizations

Apart from presentations and in-depth discussions on the dominant metallization technologies, the Metallization Workshop also offers a stage for alternative or emerging metallization techniques. In this 5$^{th}$ Metallization Workshop this topic was of greater importance than in previous editions, reflecting a sustained and continued drive for innovation in the field of metallization.

Al PVD is a well-established metallization technique for numerous applications which however has not been adopted in a significant way in solar cell manufacturing so far. That might change in the future as Interdigitated Back-Contact (IBC) solar cells become more and more widespread. Indeed, IBC cells need a large metal fraction at the rear. Moreover, as all metal contacts are on the rear surface, the structure offers the possibility to achieve the complete metallization by deposition of a blanket layer followed by local patterning. These two factors make Al PVD particularly attractive for this type of cells. Low-cost Al patterning is a key need to implement this metallization. At the workshop, localized Al anodizing was introduced has a potential high-throughput option for Al patterning [50, 51].

For H-pattern cells with printed contacts, several alternative printing techniques were discussed and recent progress was presented. Parallel dispensing is such a technique, which has been under development for a while [52, 53]. At the workshop, it was shown that, while linewidth is in the same range as what can be achieved by fine-line screen printing, aspect ratio and variability are markedly better for dispensed lines, provided that appropriately modified Ag pastes are used [54, 55]. Progress on flexography, another common printing technique which is however not used in solar cell manufacturing, was also presented [56, 57]. Promising linewidths (also in the order of 30 µm) have been achieved but with low metal deposition and therefore a high line resistance. For conventional solar cells this is not useful, but it might be ideal for cells structures that are adapted to novel interconnection techniques (see section 7). Finally, two laser transfer printing techniques were presented, which have in common that they use a laser pulse to achieve transfer of metal from a carrier to the substrate, enabling fast and precise printing. The first one is Thermal Induced Nozzle Laser Induced Forward Transfer (TIN-LIFT), which relies on accurate material deformation through laser pulse control to achieve the desired contact morphology [58, 59]. The second one is Pattern Transfer Printing (PTP), which consists of a first step where a mold with the negative image of the desired pattern is filled with Ag paste, followed by the laser flash [60, 61]. With the latter technique, very narrow (< 30 µm), high aspect ratio contacts have been achieved and proof-of-concepts cells with low Ag consumption and high fill factors (up to 79 %) have already been obtained.

## 7. New interconnection and impact on metallization

A new and interesting trend was clearly apparent in the workshop. Increasingly, metallization is designed to yield best performance and/or lowest overall cost at *module* level, and not at cell level as it too often was the case in the past. Module performance and cost are already commonly considered when the optimum number of busbars has to be determined for new modules of conventional design. However, the approach has a more dramatic impact on the final metallization when new interconnection techniques or completely new module structures are implemented.

In order to reduce overall cost, attempts are being made to attach interconnection ribbons on cells without busbars. Electrically conductive adhesives (ECA) are used, but in order to make effective use of ECA and enhance adhesion, it was proposed to combine ECA and a non-conductive adhesive. Preliminary proof-of-concepts were demonstrated [62, 63].

In the case of back-contact modules based on Metallization Wrap Through cells and conductive backsheets (CBS), optimization calculations shift metallization designs to many vias, as well as very thin and narrow fingers [64, 65]. For these modules, reliable contact is required between the CBS and the ECA used to connect the cell metallization to the CBS. Certain combinations CBS-ECA with excellent durability and performance were shown to exist [66, 67].

The most dramatic impact on the module-centric design of metallization is when wire-based interconnection is implemented, such as the Smartwire or Multibusbar technologies [68]. Indeed, in these approaches, the distance between the interconnecting wires (between 15 and 30 per cell depending on the technology) is very short. As a result the finger line resistance can be high without introducing excessive resistive losses (losses being proportional to the square of the finger length). In that case, it is possible to apply fine line screen printing with very low paste lay-down and still achieve high performance [69]. High throughput fine-line techniques that would otherwise not be very suitable in conventional cells may turn out very relevant for such cell and module structures [56, 57]. Moreover, cells can be used without busbars, or only very small ones, and fingers can even be interrupted without significant power loss [22, 23]. Both measures further radically reduce Ag paste consumption.

The combination of Smartwire technology with plated metallization was also presented at the workshop [70]. Interestingly, because one can afford high line resistance, a plating stack consisting of only a few µm Ni and a Ag finish layer is sufficient to reach high laminate performance. This was demonstrated with n-PERT efficiencies above 20 % and fill factors above 77.5 %.

## 8. Debates

Many of the topics presented in this paper were discussed in detail in a ‘debate market place’ at the end of the first day of the workshop. The objective was for small groups to come to a joint answer on a number of provocative questions such as ‘Cu plating: How do we make it happen in practice ?’ or ‘Soldering ribbons at damage-inducing temperature onto material-wasting busbars : Is there a smarter way with ribbons ?’ Each topic was highlighted by one or two posters with relevant content. Before the discussion the authors presented their posters serving as the starting point for the debate and leading to very lively exchanges. The outcome of the group discussions can be found on the website of the 5$^{th}$ Metallization Workshop (access through www.metallizationworkshop.info).

## 9. Conclusion

The 5th Metallization Workshop highlighted great progress in the field of solar cell metallization. Screen printing technology is true to its impressive track record of continuous improvement, notably with fine-line screen printing (linewidth < 50 µm) becoming a reality. Ni/Cu plating technology is also progressing fast, with many of the technical barriers to adoptions being successfully removed. Finally, the workshop also highlighted the move towards a module-centric design of solar cell metallization, targeting high performance and low cost at module level.

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## References

[1] G. Schubert, F.Huster, P Fath Current transport mechanism in printed Ag thick film contacts to an n type emitter of a crystalline silicon solar cell, Proceedings 19th European Photovoltaic Solar Energy Conference, Paris, France, 2004, pp. 813-816.
[2] Ballif C, Huljic D, Willeke G, Hessler-Wyser A, Silver thick-film contacts on highly doped n-type silicon emitters: Structural and electronic properties, Applied Physics Letters, 82 (2003) 1878-1880.
[3] Cheng L K, Liang L, Li Z, Nano-Ag Colloids Assisted Tunneling Mechanism for Current Conduction in Front Contact of Crystalline Si Solar Cells, Proceedings 34th IEEE Photovoltaic Specialists Conference, 2009, pp. 2344-2348.
[4] P. Kumar, B.Willsch, M. Dürrschnabel, Z. Aabdin, R. Hönig, N. Peranio, F. Clement, D. Biro and O. Eibl Combined microstructural and electrical characterization of metallization layers in industrial solar cells, in: Presentation at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, 2014.
[5] Tetsu Takahashi, T.Senba Seiya Konno, Kazuo Muramatsu, Aki Tanaka, New Metallization Concept for High Efficiency/Low Cost c-Si Photovoltaic Solar Cells, in: Presentation at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[6], P.Kumar, Z. Aabdin , N. Peranio , O. Eibl Serial and contact resistance measurements between 80 K and room temperature for industrial solar cells Presentation at 5th Workshop on Metallization of Crystalline Solar Cells, (2014).
[7] P. Kumar, B. Willsch M. Dürrschnabel, Z. Aabdin, R. Hönig, N. Peranio, F. Clement, D. Biro and O. Eibl Combined microstructural and electrical characterization of metallization layers in industrial solar cells, *this issue of Energy Procedia*.
[8] B. Willsch, P. Kumar, Z. Aabdin , N. Peranio , O. Eibl, Series and contact resistance measurements between 80 K and room temperature for industrial solar cells, *this issue of Energy Procedia*.
[9] R. Hoenig, D. Voessing, F. Clement, D. Biro, J. Wilde, Macroscopic and microscopic electrical behavior of screen printed silver contacts to phosphorus-doped emitters, in: Presentation at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[10] Sung-Bin Cho, Hee-Soo Kim, Min-Je Hwang, Joo-Youl Huh, Effect of forming gas annealing on screen-printed Ag metallization of silicon solar cells, in: Presentation at the 5th Workshop on the Metallization of Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[11] S. Riegel, F. Mutter, T. Lauermann, B. Terheiden, G. Hahn, Review on screen printed metallization on p-type silicon, Energy Procedia, 21 (2012) 14-23.
[12] S. Fritz, König, M., Riegel, S., Herguth, A., Hörteis, M., Hahn, G., Formation of Ag/Al Screen-Printing Contacts on B Emitters, IEEE Journal of Photovoltaics, 5 (2015) 145-151.
[13] S. Fritz, S.Riegel, A. Herguth, M. König, M. Hörteis, G. Hahn, Preservation of Si Surface Structure by Ag/Al Contact Spots – an Explanatory Model, in: Presentation at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[14] S. Fritz, S.Riegel, A. Herguth, M. König, M. Hörteis, G. Hahn, Preservation of Si surface structure by AgAl contact spots – an explanatory model, *this issue of Energy Procedia*.
[15] S. Fritz, S.Riegel, Axel Herguth, Markus König, Matthias Hörteis, Giso Hahn, A phenomenological model for the contact formation of Ag/Al screen-printing pastes through SiNx:H layers, in: 29th European Photovoltaic Solar Energy Conference, Amsterdam, The Netherlands, 2014.

[16] S. Körner, F.Kiefer, R. Peibst, F. Heinemeyer, J. Krügener, M. Eberstein, Basic study on the influence of glass composition and Al content on the Ag/al paste contact formation to boron emitters, in: Presentation at the 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[17] S. Körner, F.Kiefer, R. Peibst, F. Heinemeyer, J. Krügener, M. Eberstein, Basic study on the influence of glass composition and aluminum content on the Ag/Al paste contact formation to boron emitters, *this issue of Energy Procedia*.
[18] I. Dürr, S.Hoffmann, A. Kraft, J. Bartsch, Ch. Schmiga, D. Eberlein, U. Eitner, K.-A. Weiß, H. Wirth, Metallization Material Qualification in terms of Damp Heat Induced Degradation (DHID) in: Presentation at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[19] M. König, D.Zindel, M. Hörteis, A. Spribille , T. Fellmeth, F. Clement, Screen Printing Ag Metallization Technology Meets the Challenges of Today's c-Si Solar Cells, in: Poster presentation at 5th Workshop on Metallization for Crystalline Silicone Solar Cells, Konstanz, Germany, 2014.
[20] Marco Galiazzo, Alessandro Voltan, Emiliano Bortoletto, Martina Zamuner, Marco Martire, Oscar Borsato, Matteo Bertazzo, Diego Tonini, Fine Line Double Printing and Advanced Process Control for Cell Manufacturing, in: Poster at 5th Workshop on Metallization of Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[21] Marco Galiazzo, Alessandro Voltan, Emiliano Bortoletto, Martina Zamuner, Marco Martire, Oscar Borsato, Matteo Bertazzo, Diego Tonini, Fine Line Double Printing and Advanced Process Control for Cell Manufacturing, *this issue of Energy Procedia*.
[22] P. Papet, L. Andreetta, G. Wahli, J. Meixenberger, B. Legradic, W. Frammelsberger, D. Bätzner, D. Lachenal, B. Strahm, Y. Yao, T. Söderström, J. Ufheil, A. Waltinger, J. Zhao, S. Kitada, K. Honda, F. Zicarelli Fernández ,A. Faes, N. Badel, J. Levrat, M. Despeisse, E. Vetter, A. Richter, S. Leu, Silver usage reduction for monofacial and bifacial heterojunction solar cells, in: Presentation at 5th Workshop on Metallization of Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[23] P. Papet, L. Andreetta, G. Wahli, J. Meixenberger, B. Legradic, W. Frammelsberger, D. Bätzner, D. Lachenal, B. Strahm, Y. Yao, T. Söderström, J. Ufheil, A. Waltinger, J. Zhao, S. Kitada, K. Honda, F. Zicarelli Fernández ,A. Faes, N. Badel, J. Levrat, M. Despeisse, E. Vetter, A. Richter, S. Leu, New cell metallization patterns for heterojunction solar cells interconnected by the Smart Wire Connection Technology, *this issue of Energy Procedia*.
[24] H. Hannebauer, S. Schimanke, T. Falcon, P. P. Altermatt, T. Dullweber, Optimized stencil print for low Ag paste consumption and high conversion efficiencies, in: Presentation at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[25] H. Hannebauer, S. Schimanke, T. Falcon, P. P. Altermatt, T. Dullweber, Optimized stencil print for low Ag paste consumption and high conversion efficiencies, *this issue of Energy Procedia*.
[26] B. Wind, Backside metallization of bifacial n-Pasha cells, in: Presentation at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[27] Don Wood, I.Kuzma-Filipek, Richard Russell, Filip Duerinckx, Nick Powell,, B.C. Adriana Zambova, Pierre Chevalier, Caroline Boulord,, N.Z. Alexandre Beucher, WeiWei Deng, Zhiqiang Feng, J.S. Pierre Verlinden, Guy Beaucarne, Passivated busbars from screen-printed low-temperature copper paste, Energy Procedia, 55 (2014) 724-732.
[28] Don Wood, N.Powell, Adriana Zambova, Brian Chislea, Pierre Chevalier, Caroline Boulord, Alexandre Beucher, Nicolas Zeghers, Guy Beaucarne, Izabela Kuzma-Filipek, Richard Russell, Filip Duerinckx, Jozef Szlufcik, Non-contacting Busbars for Advanced Cell Structures using Low Temperature Copper Paste, in: Presentation at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[29] Don Wood, I.Kuzma-Filipek, Richard Russell, Filip Duerinckx, Nick Powell, Adriana Zambova, Brian Chislea, Pierre Chevalier, Caroline Boulord, Alexandre Beucher, Nicolas Zeghers, Jozef Szlufcik, Guy Beaucarne, Non-Contacting busbars for advanced cell structures using low temperature copper paste, *this issue of Energy Procedia*.
[30] Manabu Yoshida, Hideo Tokuhisa, Uichi Itoh, Toshihide Kamata, Isao, S.S. Sumita, Novel Low-Temperature-Sintering Type Cu-Alloy Pastes for Silicon Solar Cells, Energy Procedia, 21 (2012) 66-74.
[31] K. Dressler, M.Rauer, M. Kaloudis, S. Dauwe, A. Herguth, G. Hahn, Non-destructive Characterization of Voids in Rear Local Contacts of PERC Type Solar Cells, in: Presentation at the 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[32] C. Kranz, B.Lim, U. Baumann, T. Dullweber, Determination of the contact resistivity of screen-printed Al contacts formed by laser contact opening, in: Presentation at the 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[33] C. Kranz, B.Lim, U. Baumann, T. Dullweber, Determination of the contact resistivity of screen-printed Al contacts formed by laser contact opening, *this issue of Energy Procedia*.
[34] Achim Kraft, Christian Wolf, Jonas Bartsch, Markus Glatthaar, Characterization of copper diffusion in silicon solar cells in: Presentation at the 5th Workshop on Metallization for Crystalline Silicon Solar Cells, 2014.
[35] Achim Kraft, Christian Wolf, Jonas Bartsch, Markus Glatthaar, Characterization of copper diffusion in silicon solar cells, *this issue of Energy Procedia*.
[36] S. Jambaldinni, J.Bartsch, A. Mondon, S. Kluska, M. Padilla, A. Buechler, M. Glatthaar, S. Glunz, Investigation of salicide process from sputtered nickel on structured SiNx ARC layers for mono-crystalline Si solar cells in: Presentation at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[37] J. Horzel, Shifting the limits with Cu based metallisation and advanced plating technology in: Presentation at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[38] Ran Chen, Wei Zhang, Xi Wang, Alison Lennon, Failure modes indentified during adhesion testing of metal fingers on silicon solar cells, in: Poster at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[39] Ran Chen, Wei Zhang, Xi Wang, Alison Lennon, Failure Modes Identified During Adhesion Testing of Metal Fingers on Silicon Solar Cells, *this issue of Energy Procedia*.
[40] R. Russell, L.Tous, H. Philipsen, J. Horzel, E. Cornagliotti, M. Ngamo, P. Choulat, R. Labie, J. Beckers, J. Bertens, M. Fujii, J. John,J. Poortmans and R. Mertens, A simple copper metallisation process for high cell efficiencies and reliable modules, in: Proceedings 27th European Photovoltaic Solar Energy Conference, Frankfurt, Germany, 2012.

[41] Andrew Mondon, J.Bartsch, Mathias Kamp, Andreas Brand, Bernd Steinhauser,Norbert Bay, Jörg Horzel, Markus Glatthaar, Stefan W. Glunz, Plated nickel-copper contacts on c-Si : From microelectronic processing to cost effective silicon solar cell production in: Proceedings 29th European Photovoltaic Solar Energy Conference, Amsterdam, The Netherlands, 2014.
[42] A. Letize, D. Cullen, B. Lee, K. Crouse, N. Bay, J. Horzel, T. Knarozovski, H. Kuehnlein, J. Bartsch, M. Glatthaar, R. Böhme, Pilot scale production and reliability testing of solar cell modules based on a low cost copper electroplating process, in: Proceedings 29th European Photovoltaic Solar Energy Conference, Amsterdam, The Netherlands, 2014.
[43] J. Horzel, N.Bay, M. Passig, M. Sieber, J. Burschik, H. Kühnlein, A. Brand, A. Letize, B. Lee, D. Weber, R. Böhme, Low cost metallisation based on Ni/Cu plating enabling high efficiency industrial solar cells, in: Proceedings 29th European Photovoltaic Solar Energy Conference, 2014.
[44] G. Cimiotti, J.Bartsch, A. Kraft, A. Mondon, M. Glatthaar, Design Rules For Solar Cells With Plated Metallization, in: Poster at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[45] G. Cimiotti, J.Bartsch, A. Kraft, A. Mondon, M. Glatthaar, Design rules for solar cells with plated metallization, *this issue of Energy Procedia*.
[46] A. Lachowicz, A.Faes, P. Papet, J. Geissbühler, J. Levrat, C. Allebé, N. Badel, J. Champliaud, F. Debrot, J. Cattin, A. Hessler-Wyser, B. Strahm, S. De Wolf, M. Despeisse, C. Ballif, Plating on Thin Conductive Oxides for Silicon Heterojunction Solar Cells, in: Presentation at 5th Workshop on Metallization of Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[47] Jonas Geissbühler, Silvia Martin de Nicolas, Monica Morales Masis, Antonin Faes, Agata Lachowicz, AndreaTomasi, Bertrand Paviet-Salomon, Bénédicte Demaurex, Johannes Seif, Niels Holms, Damien Lachenal, Pierre Papet, Nicolas Badel, Loris Barraud, Aïcha Hessler-Wyser, Antoine Descoeudres, Philipp Löper, Matthieu Despeisse, Stefaan De Wolf, Christophe Ballif Electrodeposited copper front metallization for silicon heterojunction solar cells: materials and processes, in: Presentation at 5th Workshop on Metallization of Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[48] Zhongtian Li, Pei-Chieh Hsiao, Wei Zhang, Ran Chen and Alison Lennon Patterning for Plated Heterojunction Cells, in: Presentation at 5th Workshop on Metallization of Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[49] Zhongtian Li, Pei-Chieh Hsiao, Wei Zhang, Ran Chen, Yu Yao, Pierre Papet, Alison Lennon Patterning for Plated Heterojunction Cells, *this issue of Energy Procedia*.
[50] M. Kamp, A. Maywald, J. Bartsch, R. Efinger, R. Keding, M. Glatthaar, S. W. Glunz, I. Krossing, Electrochemical Contact Separation for PVD Aluminum Back Contact Solar Cells, in: Presentation at 5th Workshop on Metallization of Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[51] M. Kamp, A. Maywald, J. Bartsch, R. Efinger, R. Keding, M. Glatthaar, S. W. Glunz, I. Krossing, Electrochemical Contact Separation for PVD Aluminum Back Contact Solar Cells, *this issue of Energy Procedia*.
[52] J. Specht, K. Zengerle, M. Pospischil, D. Erath, J. Haunschild, F. Clement, D. Biro, High aspect ratio front contacts by single step dispensing of metal pastes, in: Proceedings 25th European Photovoltaic Solar Energy Conference, Valencia, Spain, 2010.
[53] M. Pospischil, M. Klawitter, M. Kuchler, J. Specht, H. Gentischer, R. Efinger, C. Kroner, M. Luegmair, M. König, M. Hörteis, C. Mohr, L. Wende, J. Lossen, M. Weiß, O. Doll, I. Koehler, R. Zengerle, F. Clement, D. Biro, Process Development for a High-Throughput Fine Line Metallization Approach Based on Dispensing Technology, Energy Procedia, 43 (2013) 111-116.
[54] M. Pospischil, M. Kuchler, M. Klawitter, C. Rodríguez, M. Padilla, R. Efinger, M. Linse, A. Padilla, H. Gentischer, M. König, M. Hörteis, L. Wende, O. Doll, R. Zengerle, F. Clement, D. Biro, Dispensing Technology on the Route to an Industrial Metallization Process. Latest developments and results of the research project „GECKO“, in: Presentation at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[55] M. Pospischil, M. Kuchler, M. Klawitter, C. Rodríguez, M. Padilla, R. Efinger, M. Linse, A. Padilla, H. Gentischer, M. König, M. Hörteis, L. Wende, O. Doll, R. Zengerle, F. Clement, D. Biro, Dispensing Technology on the Route to an Industrial Metallization Process, *this issue of Energy Procedia*.
[56] A. Lorenz, A.Senne, J. Rohde, S. Kroh, M. Wittenberg, K. Krüger, F. Clement, D. Biro, Evaluation of flexographic printing technology for multi busbar solar cells, in: Presentation at 5$^{th}$ Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[57] A. Lorenz, A.Senne, J. Rohde, S. Kroh, M. Wittenberg, K. Krüger, F. Clement, D. Biro, Evaluation of Flexographic Printing Technology for Multi-Busbar Solar Cells, *this issue of Energy Procedia*.
[58] Michael Zenou, Lee Bar-On, Amir Saar, Zvi Kotler, Solar cell metallization by laser transfer of metal micro-droplets, in: Presentation at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[59] Michael Zenou, Lee Bar-On, Amir Saar, Zvi Kotler, Solar cell metallization by laser transfer of metal micro-droplets, *this issue of Energy Procedia*.
[60] J. Lossen, M. Matusovsky, A. Noy, Ch. Maier, M. Bähr Pattern Transfer Printing (PTP™) for solar cell metallization, in: Presentation at 5fth Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[61] J. Lossen, M. Matusovsky, A. Noy, Ch. Maier, M. Bähr Pattern Transfer Printing (PTP™) for c-Si PV solar cell metallization, *this issue of Energy Procedia*.
[62] Guy Beaucarne, I.Kuzma-Filipek, Frédérick Campeol, Richard Russell, Xue Young, Jason Wei, Yanghai Yu, Filip Duerinckx, Ribbon bonding on busbar-less cells using Electrically Conductive Adhesives : Potential and challenges, in: Poster at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[63] Guy Beaucarne, I.Kuzma-Filipek, Frédérick Campeol, Richard Russell, Xue Young, Jason Wei, Yanghai Yu, Filip Duerinckx, Innovative cell interconnection based on ribbon bonding of busbar-less cells using silicone-based electrically conductive adhesives, *this issue of Energy Procedia*.
[64] E. Bende, Cost per Wp reduction due to reduced Ag paste usage. Tabbed modules vs Conductive foil-based modules, in: Presentation at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.

[65] E.E. Bende and B.B. van Aken, The effect of reduced silver paste consumption on the cost per Wp for tab-based modules and conductive-foil based modules, *this issue of Energy Procedia*.
[66] Kees Broek, I.Bennett, Mario Kloos, Wilma Eerenstein, Back contact cells merit a sound connection to the conductive back sheet, in: Presentation at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[67] K.M. Broek, I.J.Bennett, M.J.H. Kloos, W. Eerenstein, Cross testing electrically conductive adhesives and conductive back-sheets for the ECN back-contact cell and module technology, *this issue of Energy Procedia*.
[68] Stefan Braun, Giso Hahn, Robin Nissler, Christoph Pönisch, Dirk Habermann, The multi-busbar design: an overview, Energy Procedia, 43 (2013) 86-92.
[69] A. Faes, N.Badel, M. Kiaee, M. Despeisse, J. Levrat, J. Champliaud, A. Hessler-Wyser, J. Cattin, Y. Baumgartner, B. Strahm, P., D.L. Papet, G. Wahli, Y. Yao, J. Ufheil, T. Söderström, R. Grischke, M. Gragert, J. Fleischer, P. V. Fleischer, C. Ballif, SmartWire Solar Cell Interconnection Technology, in: Poster at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.
[70] R. Russell, L.Tous, A. Uruena de Castro, I. Kuzma Filipek, D. Hendrickx, F. Duerinckx, J. Szlufcik, Y. Yao, T. Soederstroem The Potential for Cu-free Ni Plated contacts Enabled by Smart Wire Connection Technology, in: Presentation at 5th Workshop on Metallization for Crystalline Silicon Solar Cells, Konstanz, Germany, 2014.